Sensor Siting to Optimize Intrusion Detection
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Abstract

The level of physical security attained with exterior intrusion detection systems (IDSs) varies with their operating environment. Weather undermines the effectiveness of an IDS by reducing its detection capability or by causing nuisance alarms. By judicious placement of IDSs, however, it is possible to improve intrusion detection through decreasing the likelihood of environment-caused nuisance alarms. In a location where the likelihood of weather-related nuisance alarms is low, an IDS may be operated at high sensitivity, thus increasing its probability of detecting an intruder. If the location also is one where environment-dependent variability in an intruder's signature is small, an additional advantage is detection capability that is consistent and predictable. CRREL is developing software that will support security planning by relating IDS detection capability to site conditions.

Introduction

Variability in weather, state of the ground, and groundcover creates situations of poor detection capability and high rates of nuisance alarms with exterior IDSs. Whether these situations seriously affect physical security depends on the frequency, intensity and duration of their impact on the IDS in use. Depending on circumstances, there may be no choice where an IDS is placed; however, when there is flexibility in defining an IDS's detection zone, there are considerations to guide personnel in siting an IDS advantageously. The first is to locate the IDS where the likelihood of environmentally related nuisance alarms is small, so that the IDS may be operated at a high sensitivity to better ensure intrusion detection. The second is to locate the IDS where the variation in intruder signature is small, so that detection capability is consistent under a range of conditions. It must be recognized, however, that sensor siting cannot be relied upon to compensate for installing an IDS that is not suited to the operating conditions at a site.

Examples of ways to use site conditions in support of intrusion detection are presented below for general classes of IDSs. Obvious weather situations are considered first, followed by more subtle situations dependent on ground state and ground cover. Table 1 summarizes environmental influences on the various classes of IDSs.

Fence-Mounted and Alignment-Sensitive IDSs

The commonality of these systems is that windloading affects their reliability. For fence-mounted IDSs, the challenge is to distinguish between wind-induced fence movement and vibrations caused by a person cutting or climbing the fence. This is made more difficult because the stiffness of the fence, which depends on its construction and

Table 1. Classes of exterior IDSs and main environmental factors influencing reliability.

Type of IDS	*Detection criterion*	*Environmental components*	*Affected by*
Passive (thermal) infrared	Thermal contrast	Ground cover thermal radiance (magnitude, rate of change, spatial uniformity) Transmission of thermal contrast	Ground cover surface temperature (insolation, exposure, ground cover characteristics [solar albedo, thermal properties, uniformity, wetness]) Wind-induced movement of objects Fog, rain, airborne snow*
Video-motion detection	Visual contrast	Ground cover reflection of visible and near-infrared radiation (magnitude, uniformity) Visibility	Illumination (direct, diffuse, shadowing) Ground cover optical properties Fog, rain, airborne snow* Wind-induced movement of objects
Near-infrared beambreak	Beam interruption	Transmission loss	Fog, rain, airborne snow* Wind-related alignment loss Blockage by snow, vegetation
Microwave radar (bistatic, mono-static)	Characteristics of received micro–wave field	Scattering by airborne particles Reflection, attenuation at ground cover	Rain, airborne snow, fog* Wind-related alignment loss Wind-induced motion of reflecting surfaces Moisture content of ground cover Blockage by snow, vegetation
Buried electro-magnetic	Disturbances to aboveground elec-tromagnetic field	Unfrozen moisture content of soil (electrical conductivity)	Soil moisture (rainfall, thawing, influx of snow meltwater) Soil temperature (frozen, unfrozen) Wind-induced motion of standing water
Buried ground-motion (optical fiber)	Changes in light pattern	Unfrozen moisture content of soil (elastic properties, rigidity) Snow cover properties	Soil moisture content (rainfall, thawing, influx of snow melt-water) Soil temperature (frozen, unfrozen) Characteristics of snow cover (den-sity, stratigraphy, depth) Wind-induced motion of surface objects
Fence vibration	Fence motion (mechanical, optical, electric sensors)	Wind loading Precipitation impact Temperature-dependent stiffness of fence fabric Temperature-dependent coupling between sensor cables and fence fabric Ice coating Improved anchoring of fence posts in dry or frozen soil	Wind Rain Temperature Icing, snow adhesion (affect vibra-tion characteristics; nuisance alarms when shed) Soil temperature (frozen, unfrozen) and dryness
Taut wire	Wire displacement	Temperature-dependent changes in wire tension Snow and ice loading of wires	Temperature Icing, snow adhesion (collection efficiency of wire)

* Severity of transmission loss within fog, rain, or airborne snow depends upon rate of precipitation and particle sizes, on wavelength of radiation, and on length of IDS's detection zone.

maintenance and also on temperature-dependent contraction and expansion, modifies the response of the fence to any type of load (wind, human). For beambreak (active infrared) and bistatic microwave IDSs, wind action causes a gradual loss of alignment. If this results only in a reduction in signal level at the receiver, then the consequence probably is limited to a greater likelihood of nuisance alarms. This occurs because a smaller perturbation of the transmitted signal now satisfies the IDS's alarm criteria. If, however, because of the misalignment, microwave or infrared transmissions are received from outside of the detection zone, then the possibility exists that disruption of microwave or active infrared signal by an intruder within the detection zone might not result in an alarm.

Wind force on an object is proportional to the square of the wind speed and depends on the direction of the wind relative to the object. If the wind speed is reduced by one-half, the associated wind force on the IDS or fence is lessened by a factor of four. Wind loading also is reduced as the prevailing direction of the local wind is altered from near normal to the fence or the IDS line-of-sight, to a more oblique angle. One means of manipulating wind speed and wind direction in the vicinity of an IDS is to place it in the shelter zone of a building or topographic feature. The sheltered region can be quite extensive; for a structure of height H and medium density (ratio of the open area of the barrier as viewed normal to its axis, to its total vertical area; a totally impenetrable barrier has the maximum density of 100%), oriented perpendicular to the prevailing wind direction, wind speed at a downwind range of 5H to 10H is ~50% of its value in the open (upwind) area (Oke, 1987). Similarly, an elongate barrier, such as a building, may redirect the wind so that it flows roughly parallel to the long axis of the barrier, to the benefit of an IDS or fence aligned parallel to it.

Unfortunately, selective siting of fence-mounted and line-of-sight IDSs to reduce wind loading is not always feasible. First, not all detection zones can be located within the shelter of a barrier. Second, prevailing wind directions are variable, so an IDS location may not be continuously sheltered. Finally, where wind barriers are effectively used to reduce wind loading, there is the complication that wind flow through the corridors between barriers may be stronger and more erratic than in open areas. Fence-mounted IDSs exposed to such wind jets are likely to have a high incidence of nuisance alarms unless operated at a low sensitivity. If feasible, fence sections subject to heightened wind activity should not be included in the same detection zone (of a fence-mounted IDS) with fence sections sheltered from wind loading.

Buried IDSs

Buried IDSs are subject to variability in intrusion detection arising from changes in the state of the ground. Moisture content and the frozen/thawed/unfrozen condition of the soil strongly affect IDS reliability. If the IDS detects by means of an electromagnetic field set up between buried transmit and receive cables, then its detection capability depends on soil moisture content. Such IDSs have good detection capability in soil that is dry or frozen (small unfrozen water content). As the soil becomes wetter, its electrical conductivity increases, dielectric loss increases, and detection capability decreases. One often unrecognized source of soil moisture is thawing of the soil, which releases water when interstitial ice melts. This, together with the influx of water during snowmelt, causes end-of-winter to be a troublesome period for buried electromagnetic IDSs. At sites that experience ground frost, it is advantageous that the ground freeze early and remain frozen, rather than cycling through numerous transient freeze–ups and thaws.

The situation is reversed for IDSs that detect intruders on the basis of ground motion, such as fiber optic sensor systems. Detection capability is high when the ground is wet following the spring thaw and snowmelt. It diminishes as the soil drains and dries, and is even lower if the soil is hardpacked or frozen. Although increasing the sensitivity setting of the IDS may temporarily restore acceptable detection capability, there usually is a penalty in the form of more numerous nuisance alarms caused by extraneous ground motion.

The easiest means of manipulating the moisture content of the soil in which an IDS is buried is to take advantage of naturally wet and naturally dry areas that result from topographically controlled drainage. Ground motion IDSs would be preferentially buried in the former and electromagnetic IDSs would be preferentially buried in the later. This reasoning is sound provided that the site is not subject to ground frost. Where freezing of the soil does occur, frost penetration is likely to proceed more rapidly and reach greater depth in wetter soil; this is because once the soil is frozen, it conducts heat from the freezing front more readily when moist. This is favorable for buried electromagnetic IDSs and unfavorable for buried ground motion IDSs. The specific situations investigated (by means of numerical simulations of heat transfer) were silty soil of moisture content 10%, 17% or 25%, by weight, subject to each of four winter conditions ranging from mild to severe (Peck and O'Neill, 1997). Because of the deeper frost and the longer duration of freezing conditions associated with the more severe winter simulations, complete thaw of the silty soil in these situations occurs ~80 days later than with mildest winter. For buried IDSs at a site subject to soil freezing, the implication of this is that there is a seasonal reversal in whether burial in typically moist soil is favorable to detection capability. Depending on the severity of winter conditions at a site, the duration of the reversal can be a significant portion of the year.

A more involved means of manipulating the moisture content of an IDS's burial medium is to place the IDS in a fill of coarse material such as gravel. A ground motion IDS, such as a fiber optic system, typically maintains a more acceptable detection capability under winter conditions if it is buried in gravel rather than soil, provided the gravel does not become encased in ice or snow covered. This is because the characteristics (amplitude, frequency spectrum) of footstep-induced ground motion change as the soil freezes from the surface down, becoming stiffer and displacing differently under an intruder. The gravel, in contrast, displaces similarly under an intruder's feet regardless of its temperature.

If it is necessary to include wet and dry areas in the same buried IDS detection zone, controlled intrusions must be done at both to establish location-dependent differences in detection capability. A series of controlled intrusions is needed to establish the persistence of an abrupt change in detection capability following rainfall or the influx of meltwater, as well as the more gradual seasonal change in detection capability associated with extended periods of dry weather.

Passive (Thermal) Infrared IDSs

Siting criteria for reducing environmental effects on the reliability of passive infrared (PIR) IDSs are the most involved, because there are many influences on PIR detection capability and nuisance alarm rate (NAR). PIR intrusion detection is based on changes in received thermal radiance, specifically the magnitude of a change and the rate at which it occurs. This means that the solar albedos and thermal properties of objects in the PIR's detection zone strongly affect PIR reliability. The spatial scale of the change in thermal radiance also is a determining factor, i.e., a simultaneous change throughout the PIR's detection zone is ignored. This introduces a dependence on the uniformity of the ground cover (or pavement) in the PIR's detection zone. Finally, changes in surface temperature of the groundcover and pavement (and other objects, such as an intruder) are predominantly driven by incident solar radiation. So, PIR reliability also depends on sky condition (overcast or clear, vs. intermittent cloud cover) and the degree of exposure to the associated solar radiation (fully sunlit to fully shaded).

The highest likelihood of nuisance alarms corresponds to a daytime situation with intermittent cloud cover and a PIR viewing a heterogeneous groundcover, such as patches of soil and grass, that is fully exposed to solar radiation. This situation provides the spatial and temporal variability in received thermal radiance necessary to satisfy the PIR's alarm criteria. Siting the PIR such that it is viewing a uniform background (all soil, all grass, one type of pavement, etc.) would be the first step in preventing nuisance alarms by reducing the spatial variability of changes in surface temperature due to solar loading. If wind-induced motion of the grass occurs, however, then received thermal radiance is still variable because of the difference in temperature between the heated tips of the grass blades and the shaded interior of the grass cover and the underlying soil. Siting the PIR such that the background is shaded from direct sunlight should eliminate environmentally induced nuisance alarms even when the background is nonuniform.

A PIR sited so as to have a low likelihood of nuisance alarms during daylight can be operated at a high sensitivity, which favors intrusion detection, even when the intruder's thermal contrast with the background is small. Further, an intruder who crosses sunlit ground or pavement before reaching the shaded detection zone will have a strong thermal signature so that the probability that he will be detected is high.

Relating Site Conditions to IDS Reliability

As acknowledged in the introduction, there may be little or no choice where an IDS is located. Siting the IDS to enhance detection capability may not be an option. Even so, an assessment of siting effects on IDS performance is still highly worthwhile, because it directs attention to variability in detection capability from zone to zone and with changing site conditions.

Consider a perimeter that is protected with several consecutive zones of IDSs, e.g., one kilometer of chain-link fence that is divided into ten, 100-m-long zones of fence-mounted IDS. To assess site-specific effects on the reliability of fence-mounted IDSs for intrusion detection, the perimeter should be evaluated in terms of the following:

Which detection zones fall entirely within the shelter of a wind barrier?

Which detection zones include both wind-sheltered and wind-funneled areas?

How do the zones compare in terms of number of nuisance alarms on a windy day? (Alarms caused by people or animals must be excluded.)

Are all IDSs set at the same sensitivity?

Does the number of nuisance alarms from an IDS entirely in a sheltered zone increase unacceptably if that IDS's sensitivity is set higher?

If the sensitivity of an IDS exposed to wind funneling is set low to reduce the number of nuisance alarms, is its detection capability acceptable when controlled intrusions are done at relatively sheltered fence sections within that detection zone?

Which zones are shaded from incident solar radiation?

Do daytime (nighttime) nuisance alarms coincide with warming (cooling) of the fence?

A similar series of questions would be asked with regard to buried IDSs and passive infrared IDSs to delineate differences in detection capability related to soil wetness and to uniformity of ground cover, respectively. For buried IDSs in 100-m-long zones along the perimeter:

Which detection zones fall entirely within well-drained soil?

Which detection zones include both areas of relatively wet and relatively dry soil?

Is the IDS set at the same sensitivity in each zone?

When security personnel perform controlled intrusions to validate the current detection capability of the buried electromagnetic (ground motion) IDS, is the ratio of detections to attempts higher (lower) in an area of dry soil?

Is the reverse true for an area of wet soil?

At a given location, are there significant changes in detection capability with time since the last rainfall?

Does the number of nuisance alarms on a windy day depend on whether the soil is wet or dry, or frozen or unfrozen?

For the passive infrared IDS in 100-m-long zones along the perimeter:

Which detection zones include a single type of groundcover or pavement?

If the detection zone has a single type of ground cover, how uniform is it – e.g., entirely soil, entirely grass, a heterogeneous distribution of grass and soil patches?

Which detection zones are in the shadow of an obstacle to incident solar radiation?

Is a detection zone in shadow throughout daylight, only in morning or only in afternoon?

How do the zones compare in terms of number of nuisance alarms during the daytime on a sunny day? On a day with intermittent cloud cover?

Does the occurrence of nuisance alarms coincide with a zone's exposure to solar loading?
Does the occurrence of nuisance alarms coincide with wind activity?
Is the IDS set at the same sensitivity in each zone?
Does the number of nuisance alarms from a shadowed zone increase unacceptably if the IDS's sensitivity is set higher for those zones?
When controlled intrusions are done in the daytime, does the ratio of detections to attempts vary with the type of ground cover or pavement, or with the uniformity of the ground cover?
Does the ratio of detections to attempts vary with whether the zone is sunlit or shaded?

For the IDS examples discussed, the primary environmental factors in detection capability and nuisance alarm occurrence are easily observed (wind speed and direction; soil wetness; ground cover/pavement, exposure to solar radiation). By relating IDS reliability to these factors, security personnel can develop a high awareness of location-dependent differences in detection capability. By making note of changes in site conditions, security personnel can anticipate the consequential changes in IDS probability of detection (P_d) and NAR, and their expected duration. Site conditions change on time scales that are diurnal (daytime/nighttime differences in incident solar radiation and wind activity), seasonal (state of the ground; type of ground cover; range and rate of change of both ground cover surface temperatures and near-surface soil temperatures) and quasi-periodic (storms). For passive infrared IDSs, which often are used for force protection in tactical situations, site conditions can change simply because an IDS is relocated in conjunction with deployments of troops.

Weather Vulnerability Assessment Tool

In order to employ IDSs in physical security and force protection most effectively, security personnel must be aware that IDS reliability is a function of their site-specific conditions. General information on which, when and why site conditions affect sensor system performance (e.g., Ryerson and Peck, 1995) is available to security personnel. The questions listed above would further guide them in identifying environmentally dependent changes in IDS performance specific to their site. The level of understanding of sensor/environment interaction, however, will vary among individuals, and their response to the associated security vulnerabilities will be inconsistent. In general, security personnel would benefit from additional resources (consultations, training, decision aids).

To address the need for a means of relating IDS detection capability to dynamic site conditions, CRREL is developing the Weather Vulnerability Assessment Tool (WVAT). This is a computer application designed to evaluate the influence of primary factors (weather, state of the ground and ground cover; Table 2) and secondary factors (intruder characteristics, system sensitivity) on the results of detection trials, and to extrapolate from those results the system's probable detection capability under other site conditions. In doing so, WVAT will alert the operator to potential situations of security vulnerabilities in terms of unacceptable P_d or NAR. By extrapolating performance data to a wider range of dynamic conditions, WVAT will provide guidance to enable effective utilization of IDSs and so reduce the potential for security lapses.

Table 2. Environmental factors in WVAT evaluation of detection capability.

Category	Factors
Weather	
Wind	Speed, direction
Temperature	Air temperature
Solar loading	High, low, intermittent; uniformity
Obscuration	Type (rain, falling snow, blowing snow, fog, icing); intensity
Ground state	Frozen, unfrozen, thawing, hard-packed; wetness
Ground cover	Type (snow, vegetation, soil, pavement); rate of change of temperature; wetness; uniformity

In fixed-facility physical security, WVAT has application to all stages when a sensor system's detection capability comes into question, from qualification tests during system development, through acceptance trials for determining if an installed system meets contract specifications, to day-in/day-out operations when security personnel need to know that their IDS is continuing to provide the required detection capability. WVAT also has application in planning and conducting force protection, by alerting operators to situations (weather events, daytime/nighttime scenarios) in which the likelihood of detecting an intruder falls below a specified Pd. Another WVAT application is in specifying the site conditions under which tests/trials should be conducted; by identifying (and testing under) situations that would challenge a sensor's detection capability, a more realistic assessment of system performance and reliability may be obtained.

Summary

An IDS's long-term reliability can be improved by taking advantage of site-specific options for locating the IDS that make it less susceptible to changes in detection capability caused by dynamic site conditions. Awareness of sensor/environment interaction can guide security personnel in identifying location-dependent differences in detection capability. WVAT will assist personnel in maintaining a high level of physical security/force protection by predicting IDS P_d and NAR as a function of variability in weather, state of the ground and ground cover.

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